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Estimated Detection System False Alarms from Cargo Compartment Fire Extinguisher Discharge Statistics

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16. Abstract

Data on aircraft fleet service difficulties between 1988 and 1990 were used to estimate fire detector false alarms in the domestic commercial jet fleet. For Class C cargo compartments, data on fleet composition and utilization were used to establish false alarm rates using two levels of analytical detail. False alarms for engine nacelles, auxiliary power units, bleed air ducts, lavatories, wheel wells, and electrical and electronic bays are also considered. This treatment of false alarms is based on statistical documentation of fleet discharge events for halon extinguishing agent bottles.

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EXECUTIVE SUMMARY

Published estimates of discharges of halon extinguisher bottles were used to develop a baseline for fire detector alarm rates aboard domestic aircraft. Alarm rates were shown to be 88 per million departures for cargo compartments, 23 per million departures for engine nacelles, and 17 per million departures for auxiliary power units. The alarm rate for cargo compartments was shown to be equal to the false alarm rate by evaluation of statistics on in-flight fire and smoke incidents and accidents. The alarm and false alarm rates were shown to be sensitive to the assumptions made, the data bases employed, and fleet utilization data. Estimation of detector alarm rates from halon discharges is not a suitable methodology for detectors in lavatories, electrical and electronic bays, bleed air duct enclosures, or wheelwells. There is a need for application of statistical methods that can indicate the accuracy and reliability of alarm and false alarm rates derived from extinguishing agent bottle discharges.

INTRODUCTION

PURPOSE.

Research to develop superior on-board aircraft fire detection and suppression capability is contingent on improved systems being demonstrably more effective than in-service equipment as well as less prone to service problems such as false alarms and equipment malfunctions. Such comparisons require benchmarking the performance of in-service systems. While an extinguishing agent's relative performance can be derived from experimental data, detector false alarm propensity is best determined from actual service experience. The purpose of this work is the establishment of a false alarm baseline for present day cargo compartment detector installations. The fact that the accuracy of this baseline is limited by the accuracy and completeness of the input data, by the assumptions made, and by the methodology employed must be taken into consideration.

BACKGROUND.

Due to the potentially disastrous consequences of in-flight fires, specific regulations have been established for installation and certification of fire or smoke detectors aboard commercial aircraft. These Federal Aviation Regulations (FAR) for cargo compartments include FAR 25.855, 25.857, 25.858, 125.119; Special Federal Aviation Regulations (SFAR) 41 and 29; and Federal Aviation Administration (FAA) Technical Standard Orders (TSO) TSO-Clc, TSO-Clld, and TSO-C79. Technical guidance on detectors is further available in the Society of Automotive Engineers Aerospace Standard AS 8036, AS 400A; Radio Technical Commission for Aeronautics Document RTCA DO-160B; and FAA Advisory Circulars (AC) AC 25-7 and AC 25-9A. Only Class C cargo compartments are required to have detection and extinguishing systems. Class D compartments are designed to control fire by oxygen starvation. Class E compartments have detectors but rely on aircraft depressurization for control of the fire. Class B compartments have detectors but can have options (including flooding the compartment with an extinguishing agent) for control of the fire.

Common cargo compartment configurations include _in situ_ ionization detectors, _in situ_ light scattering detectors, and aspirating light scattering detectors wherein air from the cargo compartment is carried to the detector through a tubing network. FAR 25.858 requires the cargo compartment detection system to give a visual indication on the flight deck within 1 minute, fire detection to occur at temperatures below those which would decrease the aircraft structural integrity, the detector system to have a means whereby the flight crew could check the circuit functionality during flight, and that the detector system be effective for all approved operating conditions. To obtain FAA acceptance of a given detection system, the applicant submits designs, specifications, and data that show the system complies with the TSO. The applicant also submits a flight test plan for demonstrating the compliance of the detection system with the 1-minute rule for detection of smoke.

Besides Class C cargo compartments, other aircraft fire detector locations include engine nacelles, electronic compartments, auxiliary power units (APU's), hot bleed air ducts, and wheelwells. Flight deck operated fire suppression systems are also associated with the nacelle and APU detectors.

Published literature on aircraft fire detection is minimal. Most information is found in the cited standards and guidance material, product descriptive materials, manuals developed by manufacturers, and public and proprietary data bases.

OBJECTIVE.

The objective of this report is the establishment of aircraft baseline data for fire detector false alarms by means of published data on aircraft extinguisher agent discharge events and through the use of other available data on aircraft operations and safety.

CARGO COMPARTMENT FALSE ALARMS

METHODOLOGY.

In development of halon discharge estimates derived in reference 1, the starting point was the FAA Service Difficulty Report System (SDRS). All referenced halon discharges for the period July 1988 through June 1990 were tabulated by aircraft model and location as shown in table 1. Because not all events find their way into the SDRS, a correction factor is needed to convert this data to an estimate of the true total number of halon bottles discharged. The correction factor used was 3.33. It was found by statistically analyzing the SDRS data with a proprietary database on McDonnell Douglas aircraft service experience. This factor then was applied to each data point in table 1 to yield a total number of bottles discharged as shown in table 2. For the purposes of this evaluation, table 2 will also be assumed to be the number of false alarms as it will be shown that the actual number of fires is much lower. Some of the major sources of error are associated with two assumptions: (1) that a single correction factor can be applied to all aircraft models and all locations on a given model and (2) that the accuracy of the SDRS record is uniform across models and locations. Additionally, table 2 refers to estimates of bottles discharged rather than discharge events. In a portion of these cases, a discharge event does involve two bottles. Thus, this particular error would make the transformation of table 2 to false alarm incidents result in too high an estimate—but less than a factor of two.

TABLE 1. SDRS DATA BASE BOTTLE DISCHARGES COUNTED JULY 1988 - JUNE 1990

MODEL	CABIN	APU	ENGINE	CARGO
DC 8	2	0	13	0
DC 9/MD 80	7	4	8	0
DC 10	4	5	1	1
B707	0	0	2	0
B727	10	16	23	1
B737	4	31	6	0
B747	9	4	27	17
B757	5	0	0	5
B767	5	2	0	2
A300	2	0	2	3
A320	0	0	0	1
BAC111	0	0	2	0
L1011	16	2	2	0
F28	0	1	0	0
TOTAL	64	65	86	30

TABLE 2. ESTIMATED BOTTLES DISCHARGED JULY 1988 - JUNE 1990

MODEL	CABIN	APU	ENGINE	CARGO
DC 8	6.67	–	43.2	–
DC 9/MD 80	23.3	13.3	26.6	–
DC 10	13.3	16.6	3.33	3.33
B707	–	–	21.6	–
B727	33.3	53.3	76.6	–
B737	13.3	103.0	20.0	–
B747	30.0	13.3	89.9	56.6
B757	16.6	0	0	16.6
B767	16.6	6.67	0	6.67
A300	6.67	0	6.67	10.0
A320	0	0	0	3.33
BAC111	0	0	6.67	–
L1011	53.3	6.67	6.67	0
F28	0	3.33	0	–
Total	213.04	216.17	301.24	96.53
Estimated Grand Total = 827 Bottles				

STATISTICS.

Aircraft accident statistics are typically presented as accidents per departure, accidents per flight hour, and annual fatalities. The accidents can be qualified as fatal accidents or hull loss accidents. Clearly, generation of these numbers requires information on the population of aircraft models, duration of flights, number of departures, and number and type of accidents. Reference 1 employs McDonnell Douglas provided information on fleet size and fleet distribution which is shown in tables 3 and 4 respectively.

TABLE 3. DOMESTIC CIVIL FLEET SIZE ESTIMATES BY YEAR

Aircraft Type	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Narrow Body										
Passenger	2359	2399	2441	2490	2536	2564	2608	2645	2674	2703
Freighter	222	228	234	240	246	258	270	282	294	305
Medium and Wide Body										
Passenger	1216	1272	1334	1397	1465	1532	1613	1683	1770	1843
Freighter	200	209	219	228	239	252	265	278	291	305

TABLE 4. FLEET DISTRIBUTION (1988 - 1990)

Aircraft Type	Average Fleet	Total Engines
Narrow Body		
F28	47	94
BAC111	9	18
DC 9/MD 80	965	1930
B727	1108	3324
B737	706	1412
B757	149	298
A320	10	20
DC 8	164	656
B707	29	116
TOTAL	3187	7868
Wide Body		
DC 10	183	549
B747	192	768
B767	95	190
A300	72	144
L1011	114	342
TOTAL	656	1993

The transport jet fleet hull loss accident rate has been running at 1.9 accidents per million departures worldwide [2] when the fleet portion manufactured by the former Soviet bloc is excluded. The fire initiated hull loss accident rate is 0.1 per million departures with the location of fire origin broken down as follows: hydraulic or landing gear (14 percent), cargo compartment (10 percent), electrical fire (10 percent), main cabin (14 percent), and the balance originating in engines, fuel tanks, or auxiliary power units (45 percent).

In a more detailed study of this worldwide fleet [3], over the 15 years between January 1974 and September 1989, there were a total of 15 in-flight smoke or fire incidents located in the cargo compartments. Of these, five were severe enough to be categorized as accidents and only three were fatal accidents. Since these incidents and accidents were taken from the data of 892 persistent smoke incidents over 60 million flights, the incident rate, accident rate, and fatal accident rate for cargo compartment fires transcribe to 0.25, 0.08, and 0.05 per million departures respectively. These can be compared with the hull loss rate of 0.01 per million departures that can be attributed to cargo compartment fires according to reference 3. Considering the range of these rates, it is reasonable to conclude that the number of cargo compartment fire and smoke incidents and accidents resulting in genuine (rather than false) alarms is almost certainly no more than 0.5 per million departures. Given the fact that four-fifths of the domestic fleet does not have Class C cargo compartments, the true Class C genuine alarm rate could be as low as 0.05 per million departures.

Reference 4 lists the following number of departures for United States scheduled airlines:

1988	6,699,564
1989	6,622,080
1990	6,923,593

From these figures, the mid two-year interval would show a total number of departures domestically as 13,500,000. FAA forecast information cited in reference 5 shows departure rates near 6.5 million continuing through the mid-1990's.

ESTIMATING CARGO COMPARTMENT ALARMS.

A first order estimate of false alarm rates can be achieved through the use of very broad estimates and approximations. Working from the tables and numbers stated previously, the following are assumed:

U.S. fleet size	4,000
Fleet portion with Class C cargo compartments	0.20
Discharged bottles	50 (per year)
Detector alarms	50 (per year)
Fleet activity (departures yearly per aircraft)	1,000

These figures yield an alarm rate of 63 false alarms per million domestic departures of aircraft outfitted with cargo compartment smoke detectors. This is two orders of magnitude larger than

the previously postulated genuine alarm rate of 0.5 per million departures, and thus the rate of 63 can be assumed to be the false alarm rate.

A more accurate development of false alarm rates employs more detailed analysis of the total number of departures of aircraft containing Class C cargo compartments. In the preceding example, there was an inherent assumption that the Class C equipped aircraft represented 800,000 departures yearly of the roughly 6.5 million total domestic departures. This representation arose from assuming 1,000 departures yearly for Class C equipped aircraft. Table 5 shows the fleet composition used in reference 1 along with some tabulated representative flight lengths and speeds taken either from reference 6 or estimated. The portion of domestic departures associated with Class C equipped aircraft can be estimated from this information in the following way.

- Assume that the total of yearly flights times the flight length over the speed is the same for each model—that is,

$$F_i \frac{D_i}{S_i} = K \tag{1}$$

  where K is a constant and i refers to an aircraft model.

- The total number of all domestic departures, F_T is given as,

$$F_T = \sum N_i \; F_i \tag{2}$$

  or

$$F_T = \sum N_i \; K \; \frac{S_i}{D_i} \tag{3}$$

- The portion of annual departures held by aircraft with Class C compartments is

$$R = \frac{\sum N_j \; S_j / D_j}{\sum N_i \; S_i / D_i} \tag{4}$$

where j refers to those models from table 2 that have Class C compartments. In this manner R comes out as 0.087 which is equivalent to 565,500 departures. This increases the false alarm rate to 88 per million domestic departures. This shows the sensitivity of the alarm rate estimates to the statistical assumptions used.

TABLE 5. OPERATIONAL PARAMETERS

MODEL	NUMBER	SPEED	DISTANCE
B757	149	457	1086
A320	10	445	974
A300	72	473	1207
B767	95	493	2285
B747	192	520	3060
DC 10	183	492	1493
F28	47	370	400
BAC111	9	366	409
DC 9/MD 80	965	380	500
B727	1108	430	686
B737	706	387	437
DC 8	164	450	2000
B707	29	450	2000
L1011	114	496	1498

ADDITIONAL DETECTORS

ENGINE AND APU ALARM RATES.

According to the statistical presentation in table 2, there were 301 bottle discharges in the engine nacelles of the commercial jet fleet during the sampled 2-year period. Since both narrow-body and wide-body jets are included, there is no need to estimate the relative departure frequency, as all these aircraft have engine fire detection and suppression systems. Overall, the following quantities will be assumed:

U.S. fleet size	4,000
Fleet portion affected	1.00
Discharged bottles	150 (per year)
Fleet activity (departure)	6.5 million (per year)

This leads to an alarm rate based on bottle utilization of 23 alarms per million domestic departures. Whether these are primarily false alarms requires detailed fire statistics like those applied to the cargo compartment detectors. In the cases of APU's and engine nacelles, the definition of false alarm may be problematic in comparison to cargo compartment. While cargo compartment detectors are known to alarm when exposed to dust, fog, or other particulates; nacelle and APU detectors operate generally on thermal principles.

Thus, alarms resulting in bottle discharge may signify hazardous overheat conditions even in circumstances where no fire actually took place. Such conditions could warrant appropriate engine shut down and fuel shut off. Nevertheless, extinguisher bottle discharges could be used in engine nacelle and APU applications to discriminate between alarms that signified the presence of fire and alarms that did not. Table 2 shows that there was estimated to be 216 APU extinguisher discharges during the 2-year sample period. Utilization of the same fleet statistics used for engine nacelles results in an APU alarm rate of 17 alarms per million domestic departures.

BLEED AIR DUCTS AND WHEELWELLS.

Detectors associated with bleed air duct monitoring also work on thermal principles. However, there are no extinguishing systems associated with these hot air leak detectors, so bottle discharge statistics are not relevant to the performance history of these detectors. Aircraft wheelwells also contain thermally activated fire and heat sensors. Again, there are no fire extinguishing bottles for the wheelwells so extinguishing agent utilization statistics are not useful for this application.

LAVATORIES.

Although lavatories are required to have extinguishing systems for trash bins, these systems are typically small potty bottles activated when a thermal fuse melts from heat given off in a fire. Lavatory installed smoke detectors are independent of these extinguisher bottles. As such, there is no apparent relationship between the number of lavatory bottle discharges and the number of smoke detector alarms. In the analysis documented in reference 1, lavatory bottle discharges were not tabulated.

ELECTRICAL AND ELECTRONIC (EE) BAYS.

Smoke detectors in the EE bays are generally in the equipment cooling outlet ducts. Alarms generated by these detectors require the flight deck crew to make adjustments to the equipment cooling air controls and possibly to shed some of the electronic power load. There are no extinguishing systems for the electronic bays. Countermeasures consist of eliminating the source of overheating and venting compartment smoke overboard.

DISCUSSION

Identifying safety related parameters like false alarms results in a technical base providing guidance on a number of significant issues including the following:

- Performance levels offered by new technology or new products for quantifiable safety improvements can be compared to baseline current performance.

- The cost of false alarms can be estimated, and the financial benefits of proposed improvements can be compared to the cost of installation of such improvements.

- To the extent that the statistical base can be refined to allow accuracy on a model-by-model basis, less effective or more trouble-prone detector installations can be identified.

- Comparative evaluations of the different data bases on accidents, incidents, and service difficulties could result in identification of the weakest areas of data reporting.

Halon bottle discharge events can be used to estimate detector false alarm rates for aircraft Class C cargo compartments but are more problematic if used to attempt an estimate of engine or APU false alarm rates. The bottle discharge approach is not useful for estimating fire detector false alarm rates in other important aircraft installations covering lavatories, hot bleed air ducts, EE bays, and wheelwells.

Development of false alarm rates is highly sensitive to the accuracy of the events data base as well as to assumptions and data concerning fleet composition and utilization profiles. At least in the 1988 to 1990 time frame, there would have been approximately one cargo compartment false alarm per week for domestic airline operations.

Further development of this kind of approach to performance and reliability of aircraft fire protection systems would be greatly aided by use of statistical methods that could indicate the accuracy expected of the estimates that are developed.

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